Turbulent drag reduction for a wall with a bump

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Friction Drag Reduction

Research

- Simple geometries
- Friction drag only
- (Low Reynolds number)

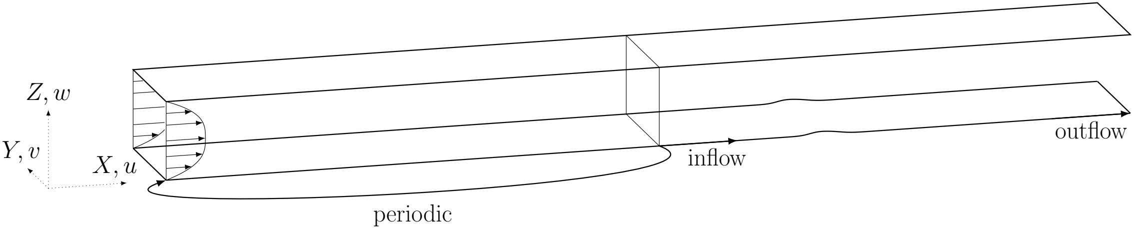
Applications

- Complex Geometries
- Pressure drag - wave drag...
- (High Reynolds number)

What is the effect of friction drag reduction on total drag?

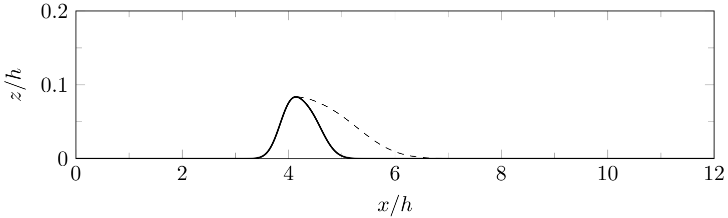
Channel with a bump

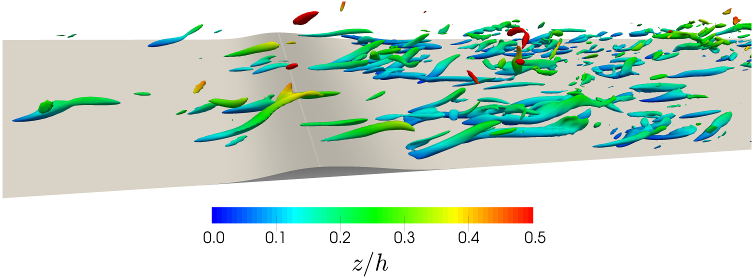
- Incompressible DNS of a channel with a small bump
- Second-order FD, immersed boundary
- Periodic + non-periodic domain
- $Re_\tau = 200$, $(L_x, L_y, L_z) = (25h, 3.2h, 2h)$, $(N_x, N_y, N_z) = (1120, 312, 241)$



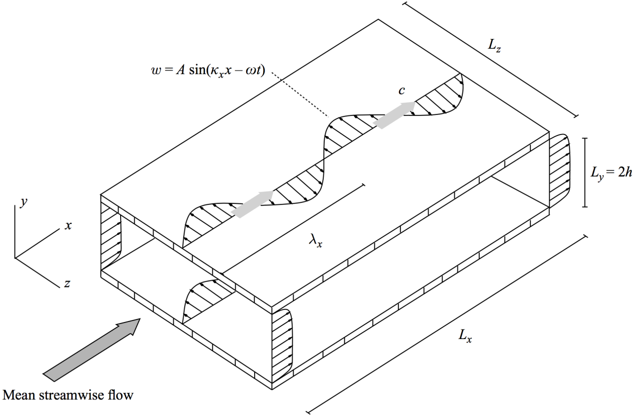
Curved wall

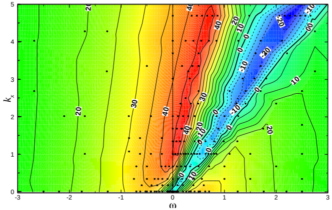
Two (small) bump geometries, one inducing mild separation





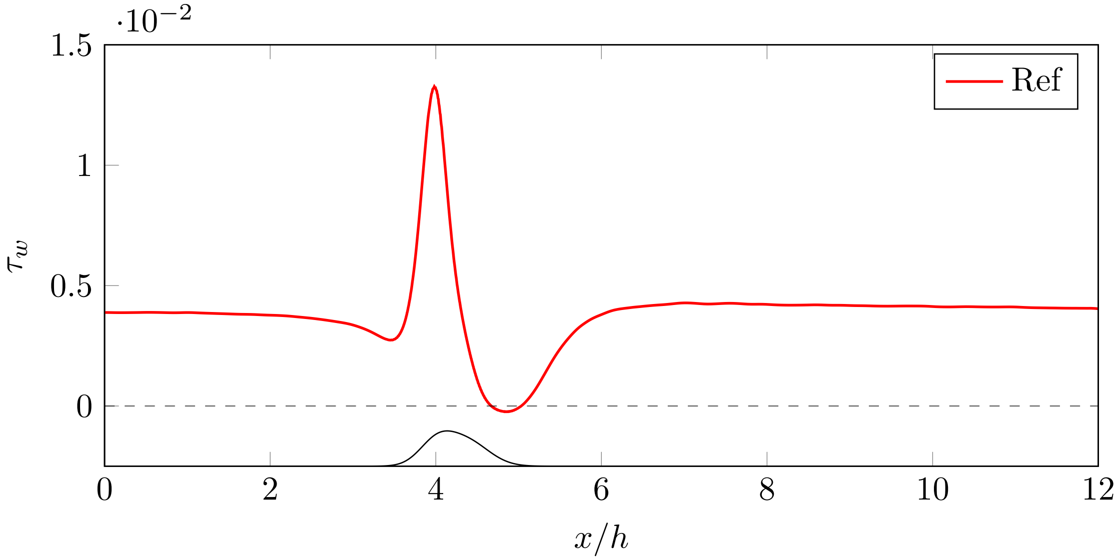
The Streamwise Travelling Waves (StTW)



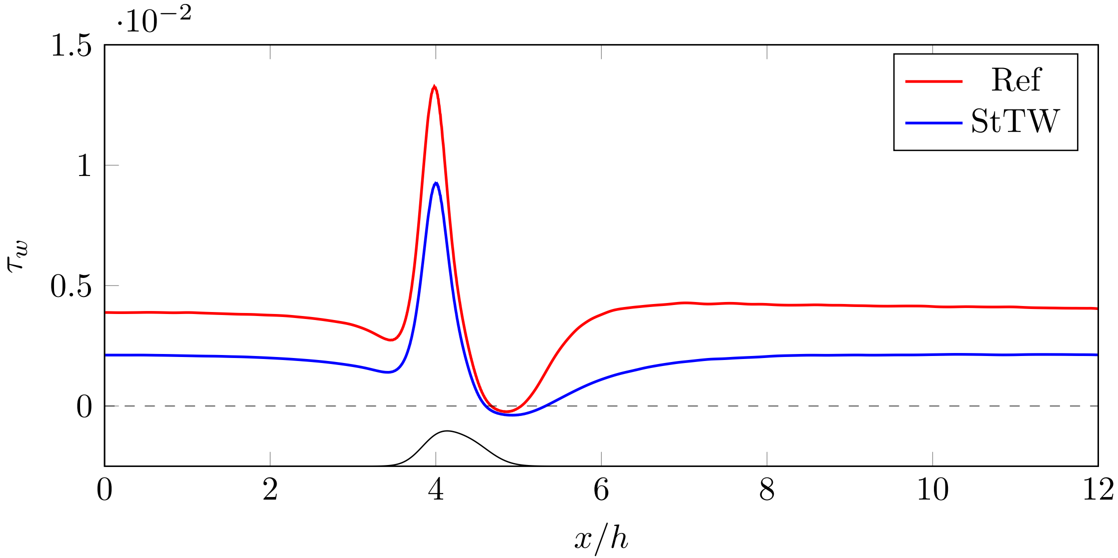


Quadrio, Ricco & Viotti, JFM 2009

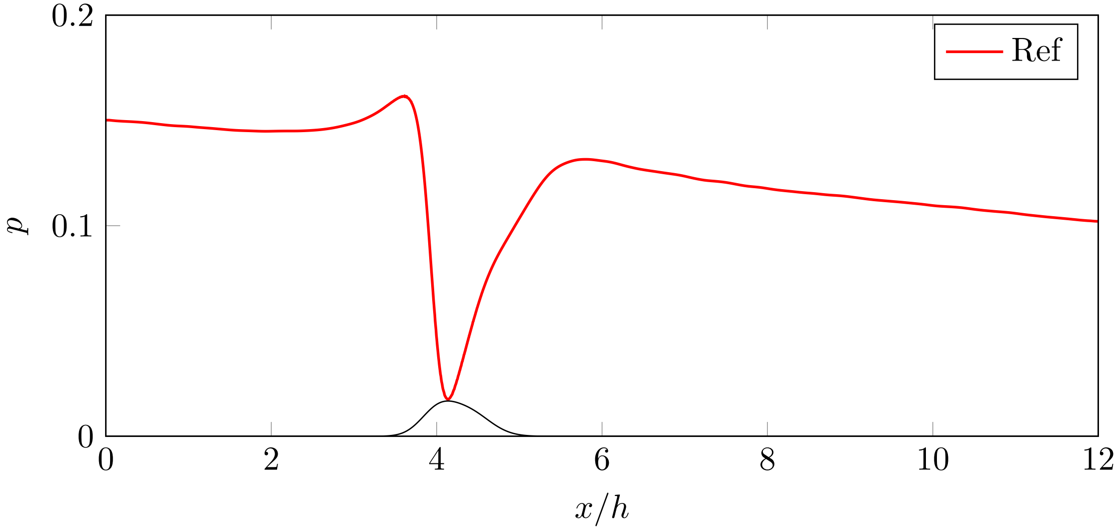
Wall shear stress



Wall shear stress



Pressure at the wall



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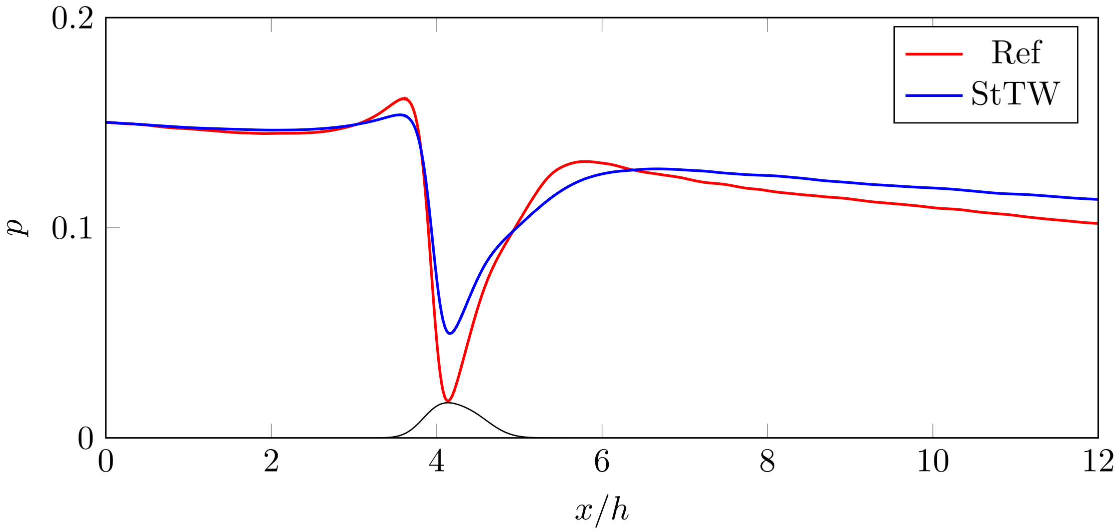
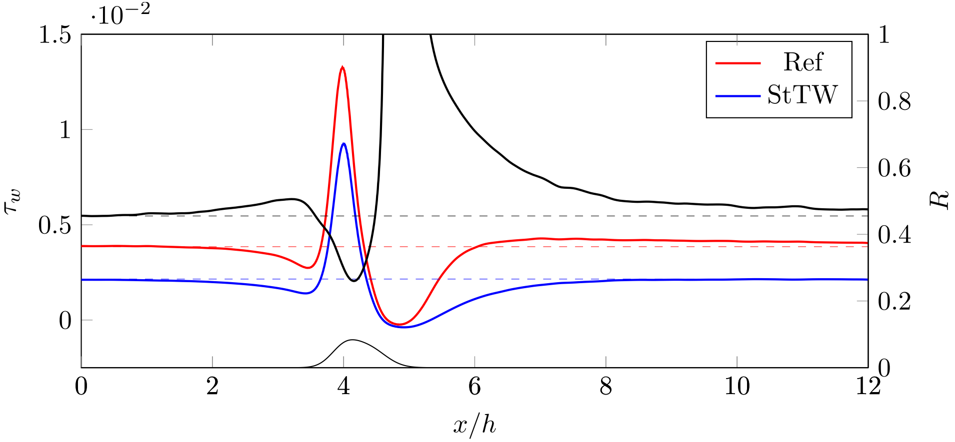


Power budget

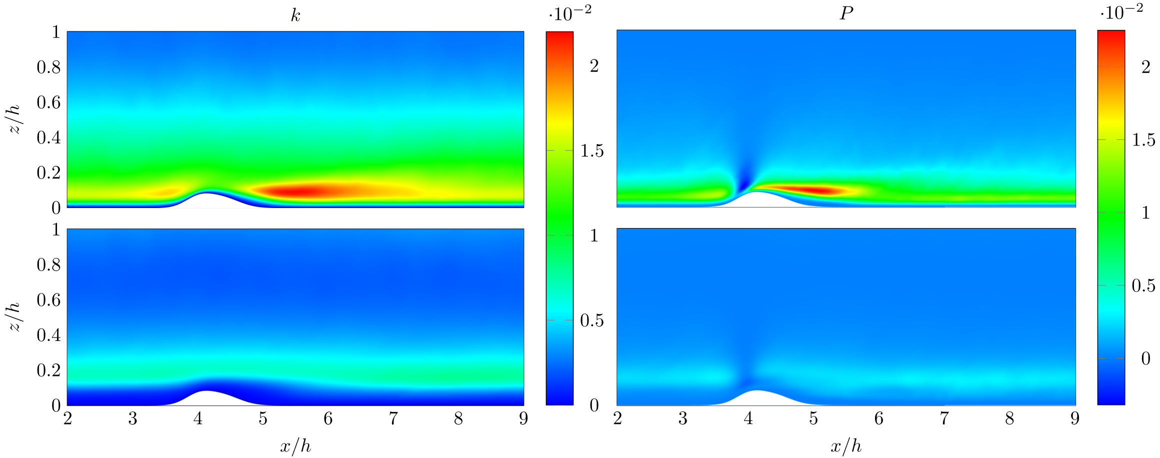
	Plane			Bump		
	Ref	StTW	Δ	Ref	StTW	Δ
P_f/P_{tot}	1	0.545	$-$**45.5%**	0.918	0.462	$-$**49.6%**
P_p/P_{tot}	–	–	–	0.082	0.073	-10.3%
Net Power Savings	–		-11.5%	–		-15.3%

Wall shear stress and friction reduction rate

$$R(x) = \frac{\tau_w(x)^{Ref} - \tau_w(x)^{StTW}}{\tau_w(x)^{Ref}}$$



TKE (left) and TKE production (right)



Conclusions

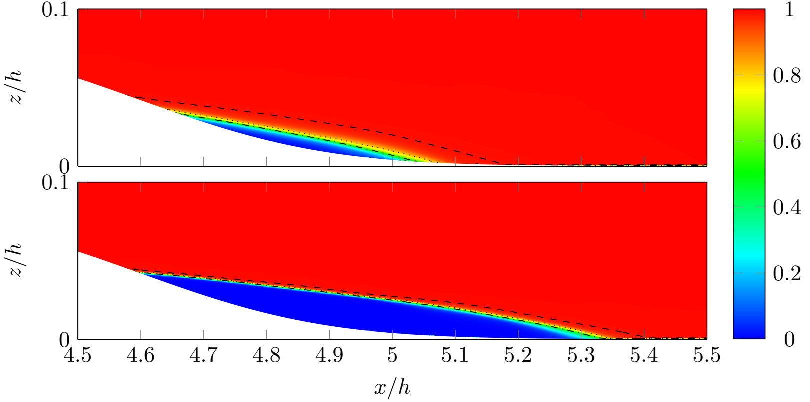
- Interaction between friction drag reduction and overall drag
- Benefits of skin-friction drag reduction techniques may be underestimated
- Compressible DNS may reveal larger effects

Thank you for your attention

Questions?

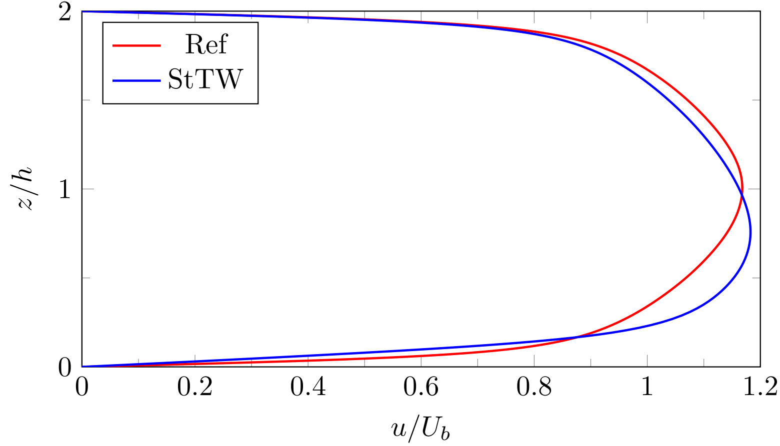
The separation bubble

Probability γ_u of a non-reversed flow:

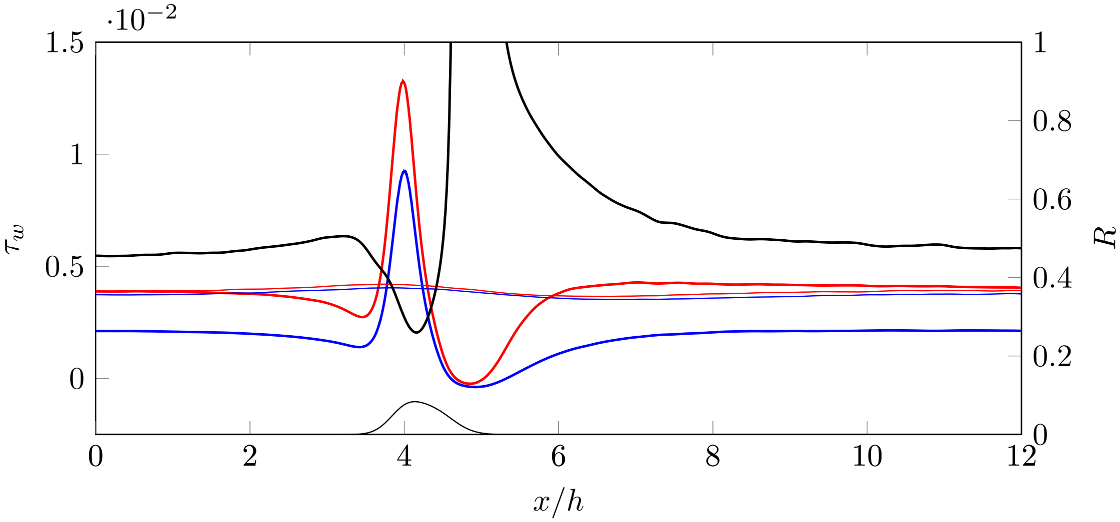


The mean velocity profile (no bump)

The maximum velocity shifts towards the actuated side and produces 4% additional drag reduction on the unactuated side!



Wall shear stress

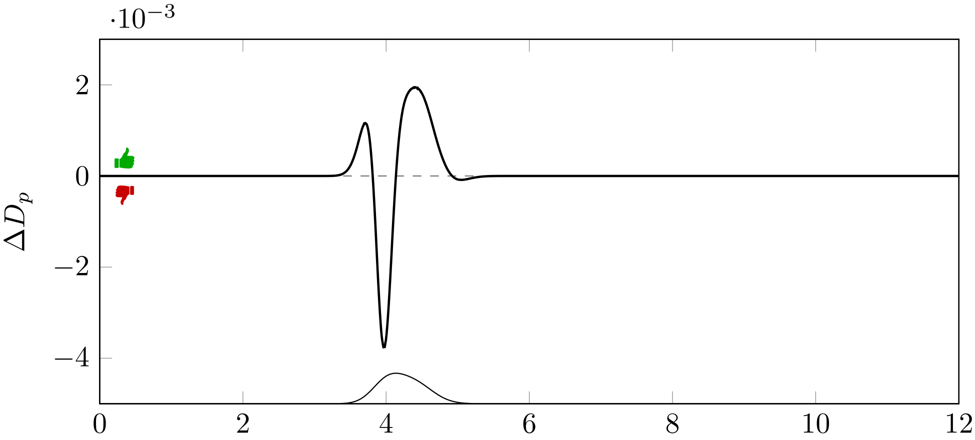


Power budget - Second Geometry

	Plane			Bump		
	Ref	StTW	Δ	Ref	StTW	Δ
P_f/P_{tot}	1	0.535	$-$**46.5%**	0.948	0.480	$-$**49.0%**
P_p/P_{tot}	–	–	–	0.060	0.058	-3.4%
Net Power Savings	–		-12.5%	–		-15.1%

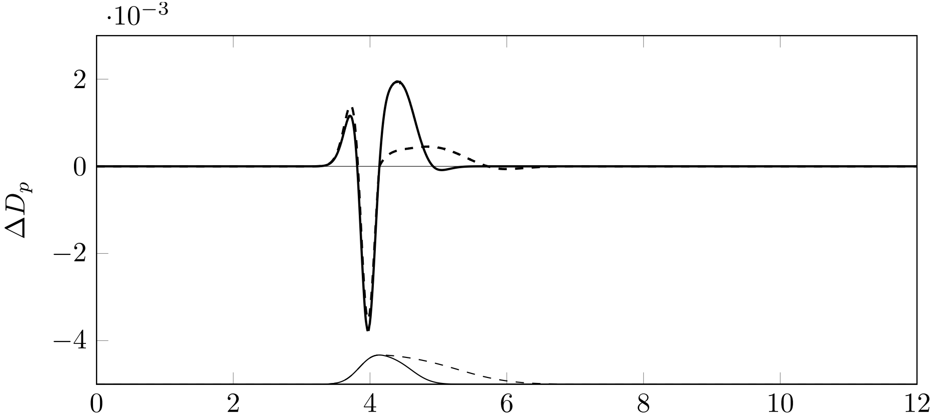
Pressure drag reduction

$$\Delta D_p(x) = D_p(x)^{Ref} - D_p(x)^{StTW}$$

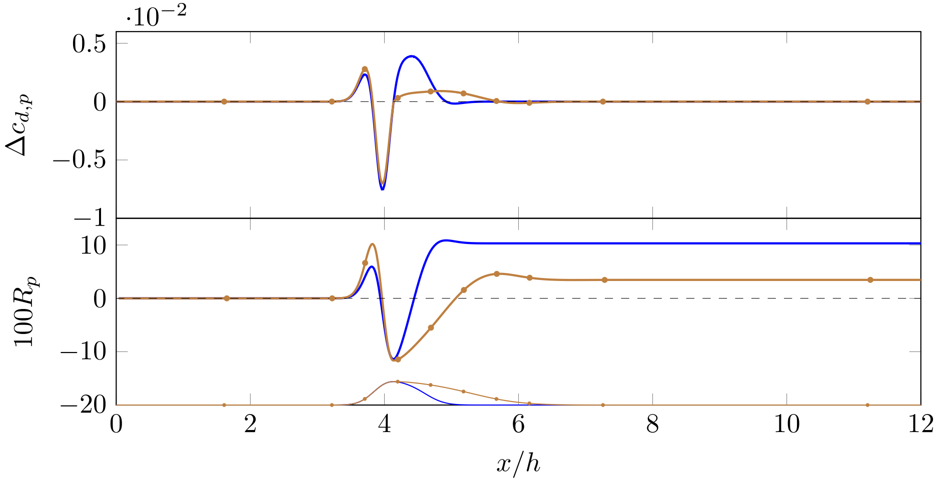


Pressure drag reduction

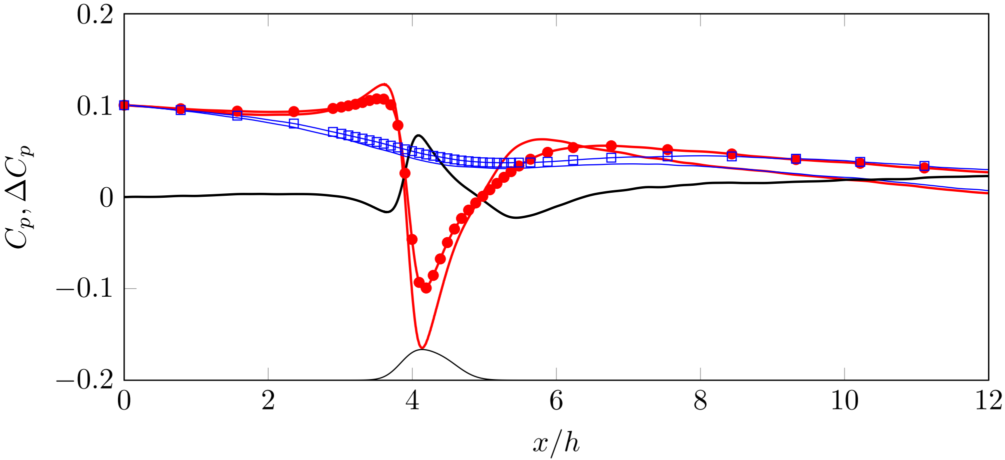
$$\Delta D_p(x) = D_p(x)^{Ref} - D_p(x)^{StTW}$$



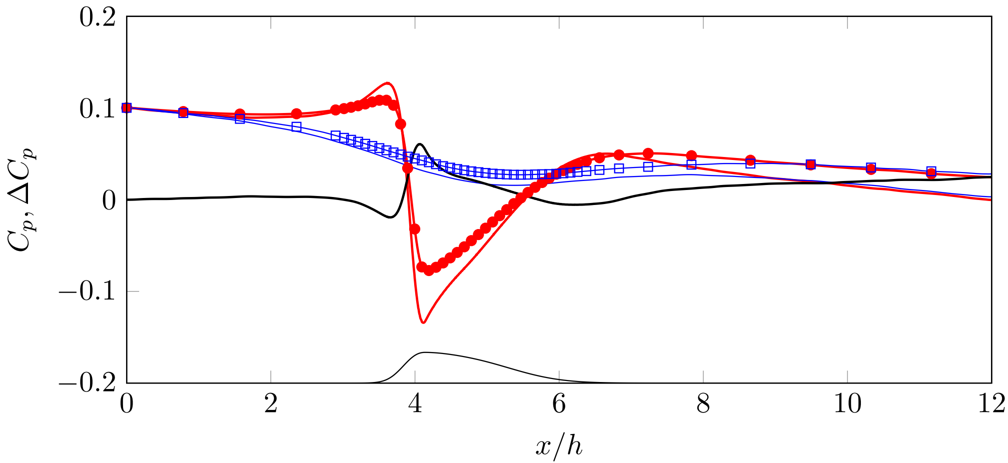
Pressure drag reduction



Pressure distribution - bump 1



Pressure distribution - bump 2

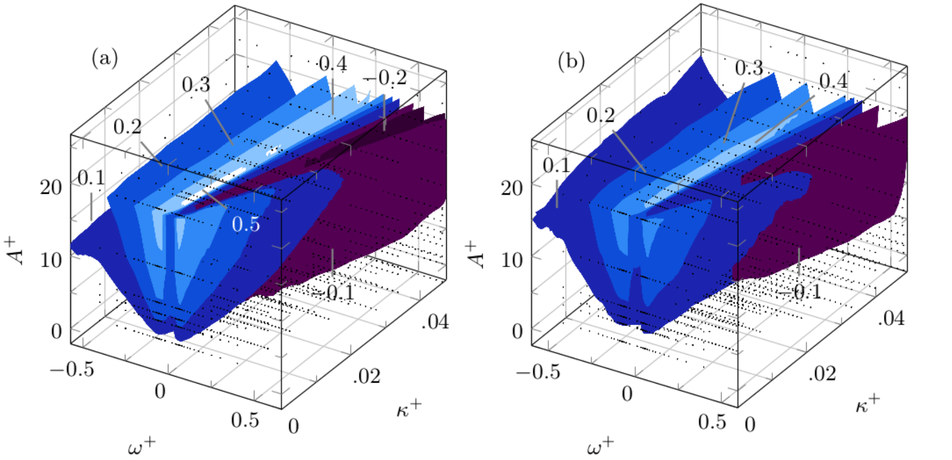


Are StTW ready for practical applications?

Besides lacking a suitable actuator,

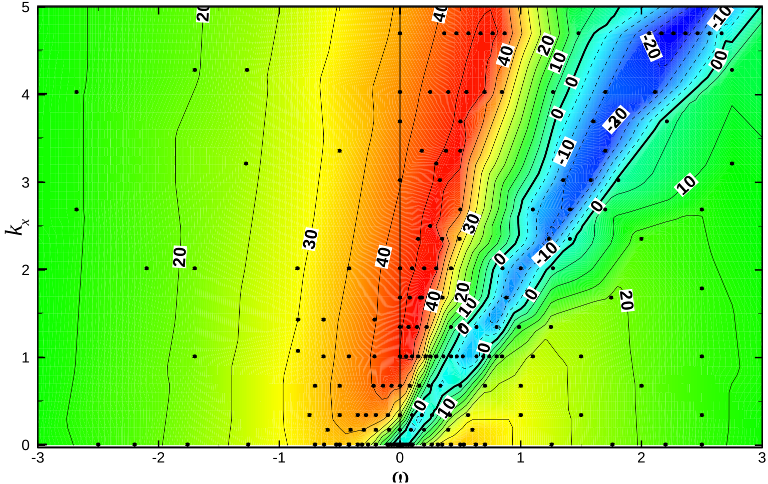
- Q1 Effect of *Re*? - Gatti & Quadrio, JFM 2016
- Q2 What about total drag?

Q1: effectiveness is constant with *Re*



Gatti & Quadrio, JFM 2016

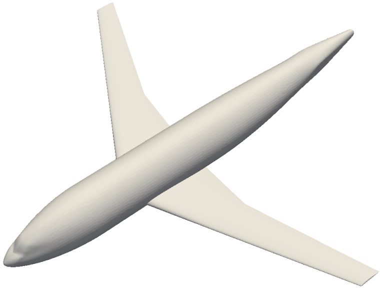
The streamwise-traveling waves (StTW)



Q2: What about the airplane total drag?

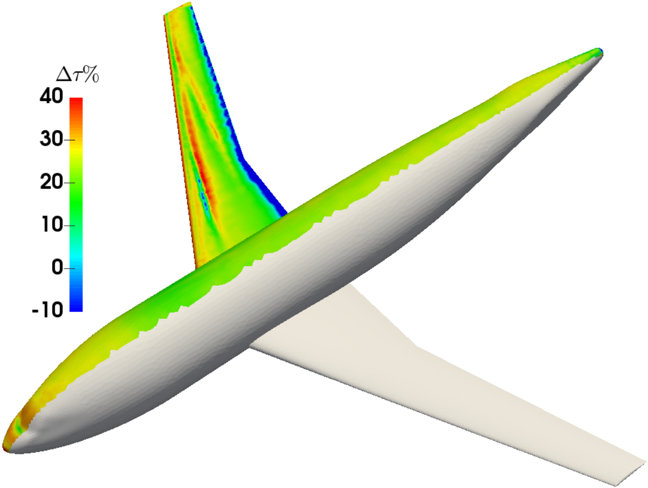
Prelim results presented at last EDRFCM in Frascati

- Transonic DLR-F6 transport aircraft
- RANS, Spalart-Allmaras model
- $Re = 3 \times 10^6$, $M = 0.75$
- StTW accounted for via wall functions



Changes in friction AND pressure

Friction drag reduces by 20% ⇒ Total drag reduction of 10%



Changes in friction AND pressure

... but due to pressure changes the total drag reduces by 15%